Huygens entry heat flux prediction

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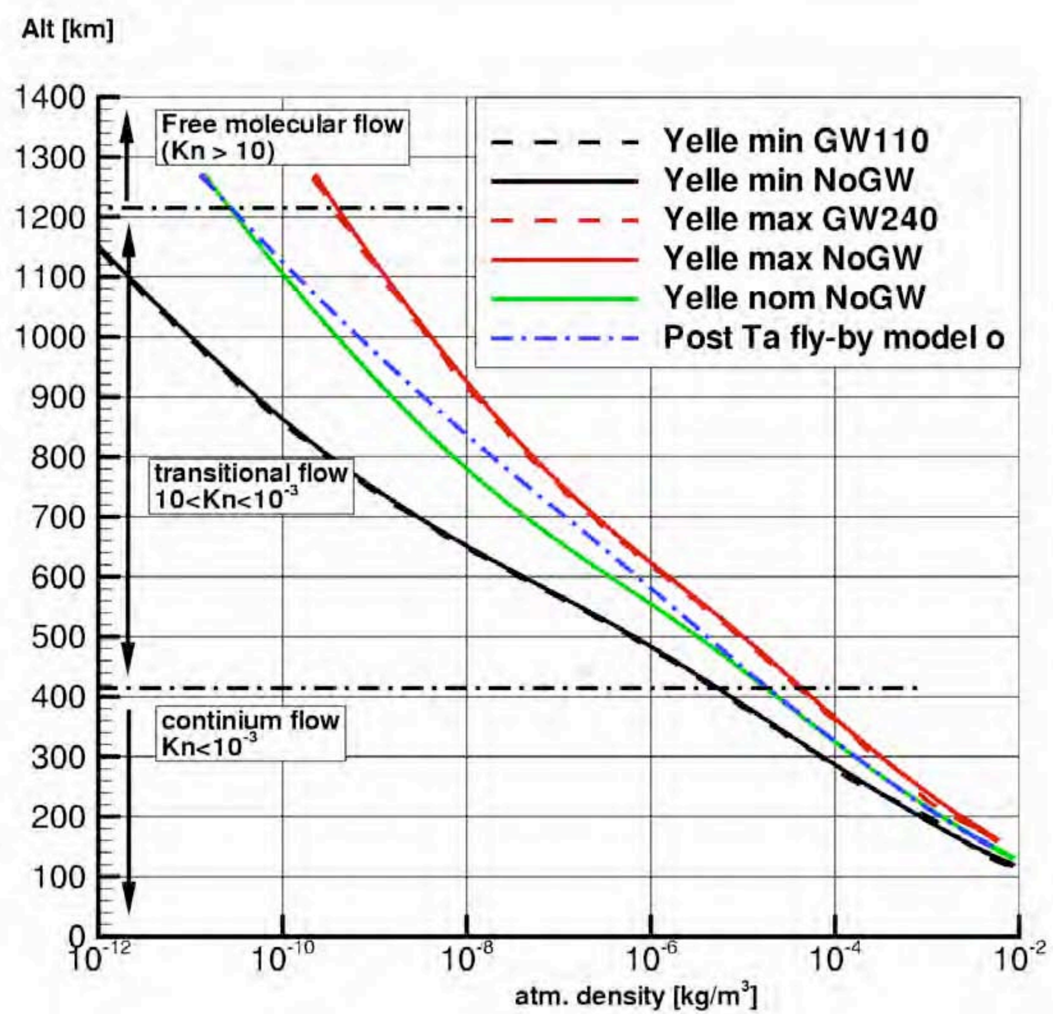
•Prior to probe release, heat flux assessment, triggered Aero Convergence Working Group (ACWG):

EADS/EM2C/ESTEC/NASA Ames/Langley

analysis focused mainly on <u>max heat flux/heat load</u> w.r.t.

- *entry angle and atmosphere composition variation based on well consolidated/validated models)*
- *Contribution of AOES/EM2C is presented:*
  - Flow field analysis (AOES) + convective heating
  - Experimentally code validated Boltzmann radiation (EM2C)

Titan atmospheric density profiles



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Summary
trajectory consolidation cases

A) TPS max heat flux sizing case: Yelle min, FPA=-68^0

- Yelle min [95%N2, 5%CH4, 0%Ar] Gravity Wave 110
- Yelle min [95%N2, 5%CH4, 0%Ar] No Gravity Wave

CH4 concentration sensitivity

to envelope TPS heat flux sizing case

- Yelle min(A) [97%N2, 3%CH4, 0%Ar] No Gravity Wave
- Yelle min(B) [99%N2, 1%CH4, 0%Ar] No Gravity Wave

Summary of heat flux consolidation cases

B) TPS heat load sizing case: Yelle max FPA=-62⁰

- Yelle max [89%N2, 1%CH4, 10%Ar] Gravity Wave phase 240 deg.
- Yelle max [89%N2, 1%CH4, 10%Ar] No Gravity Wave

Argon concentration sensitivity

- Yelle max(A) [92%N2, 1%CH4, 7%Ar] No Gravity Wave
- Yelle max(B) [97%N2, 1%CH4, 2%Ar] No Gravity Wave

Summary of heat flux consolidation cases

C) Yelle nominal case: FPA=-65^0 :

verification of the TPS design adequacy

– Yelle nom [95%N2, 3%CH4, 2%Ar] No GW

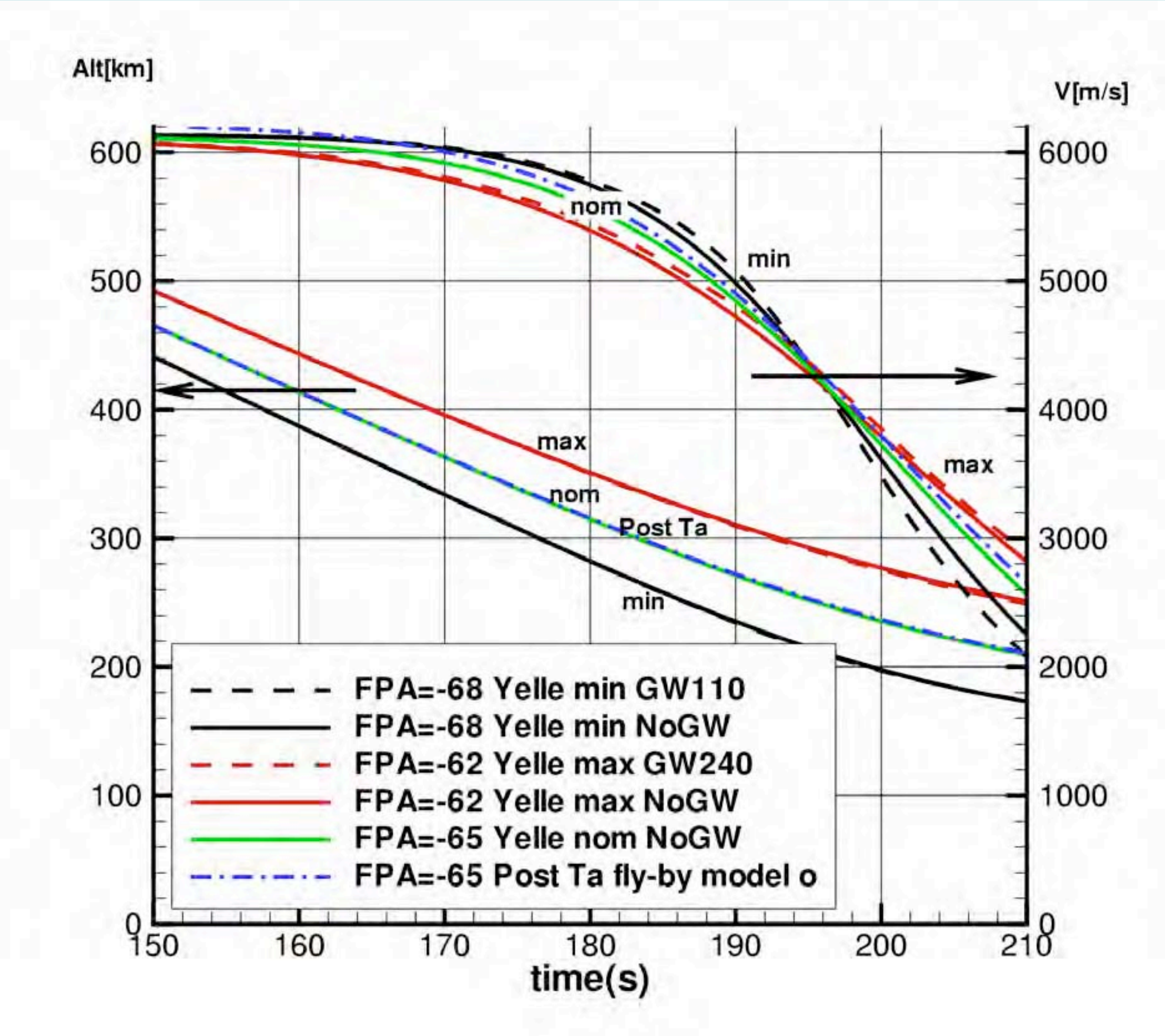
Nominal Entry – CH4/N2 concentration sensitivity

– Yelle nom(A) [96%N2, 2%CH4, 2%Ar] No GW

D) Post Ta atmosphere (26 oct 2004), FPA=-65^0 :

- Post Ta [97.7%N2, 2.3%CH4, 0%Ar] No GW
- Post Ta (A)[97.7%N2, 1.8%CH4, 0%Ar] No GW
- Post Ta (B)[97.7%N2, 3.3%CH4, 0%Ar] No GW

Associated trajectories and FPA at EI

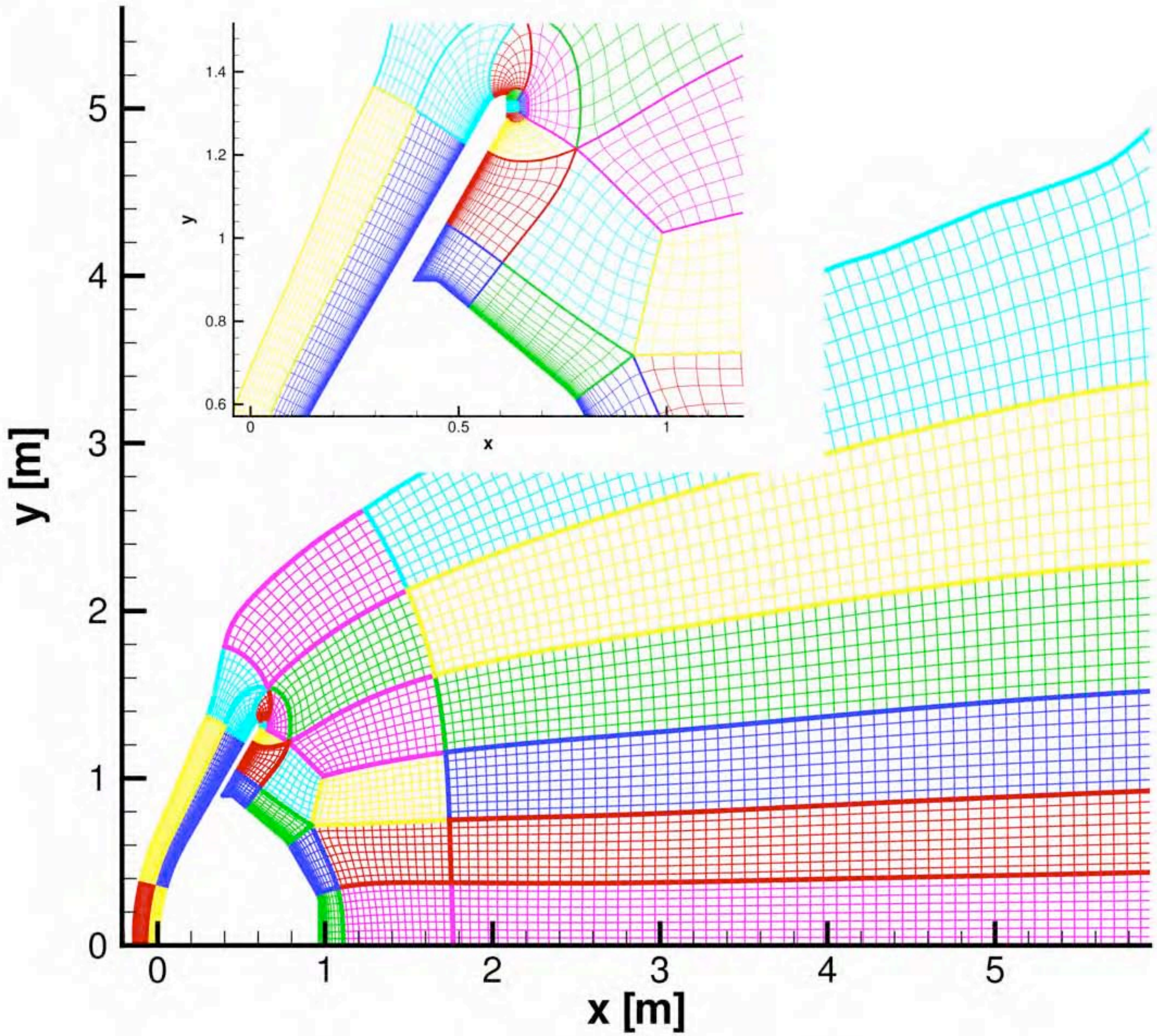


Convective heat flux analysis

CFD Navier-Stokes solver: LORE

1. Thermo-chemical nonequibrium: 2-temperature model
2. Finite volume modified AUSM/multi-block
3. Nelson(1991)/Gokcen(2004) reaction model
4. Diffusion model fixed Lewis/collision integrals
5. Special attention towards grid convergence

Convective heat flux analysis



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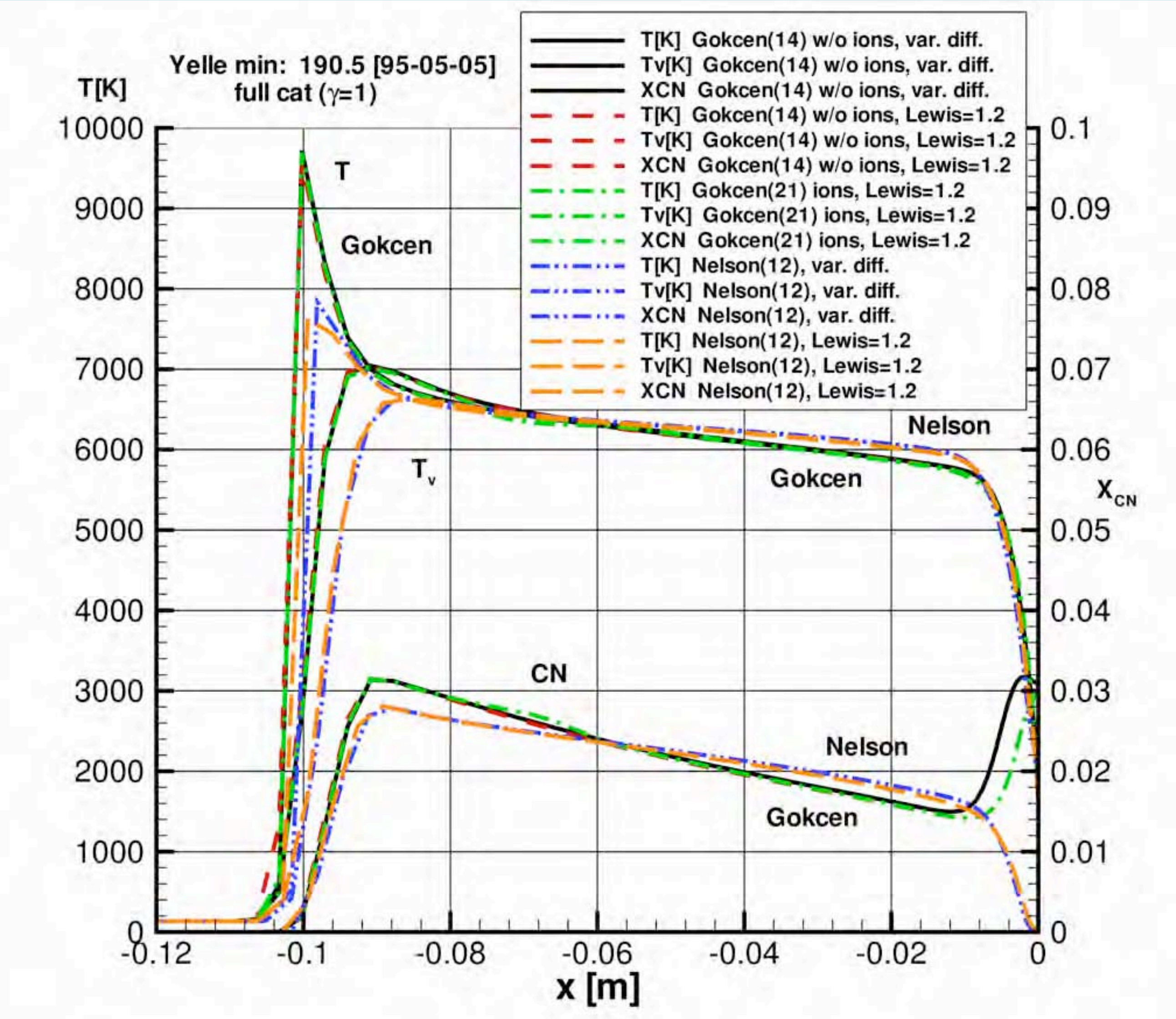
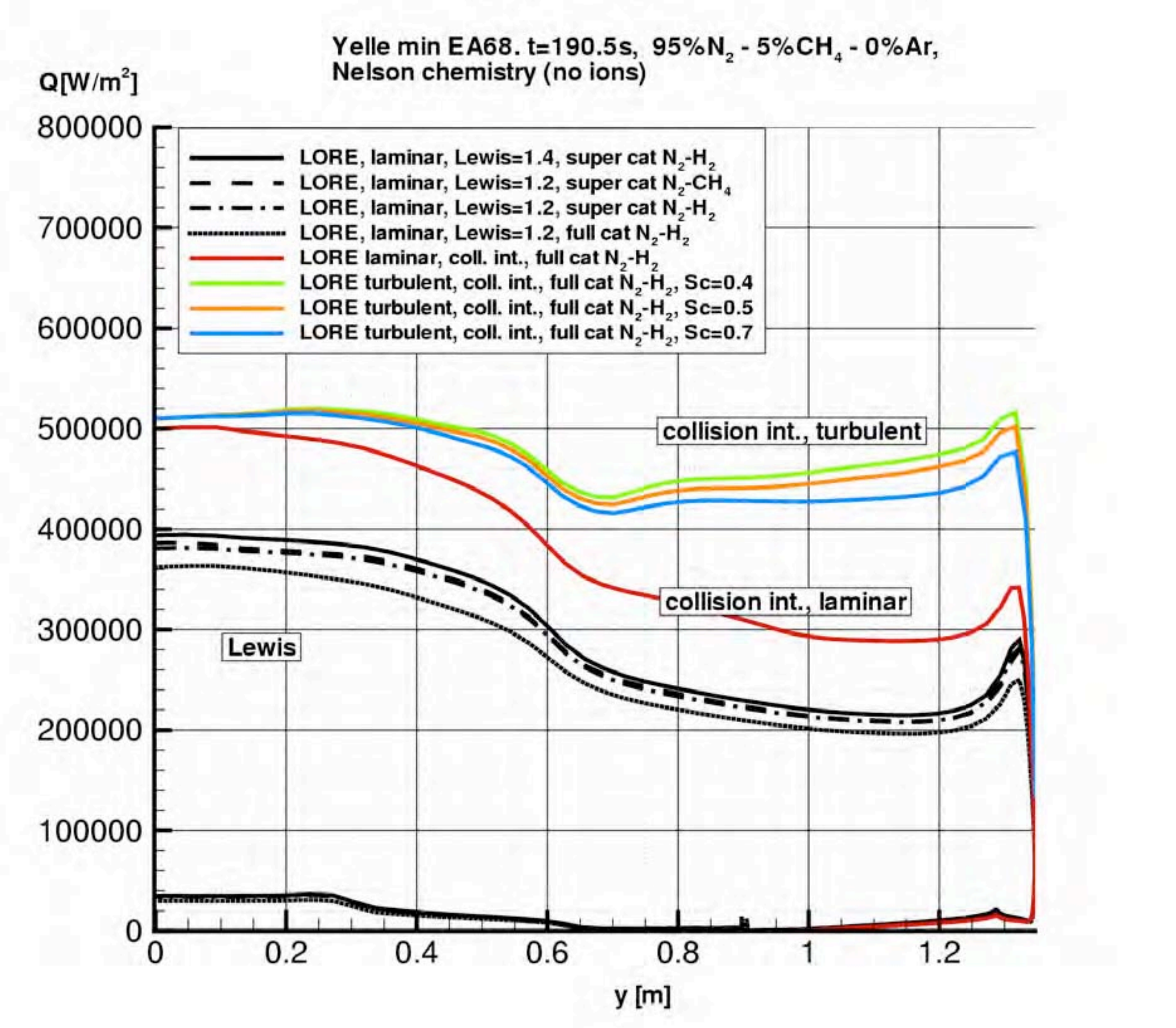
Chem reaction set influence on stagnation line (Nelson/Gokcen w/o ionization)



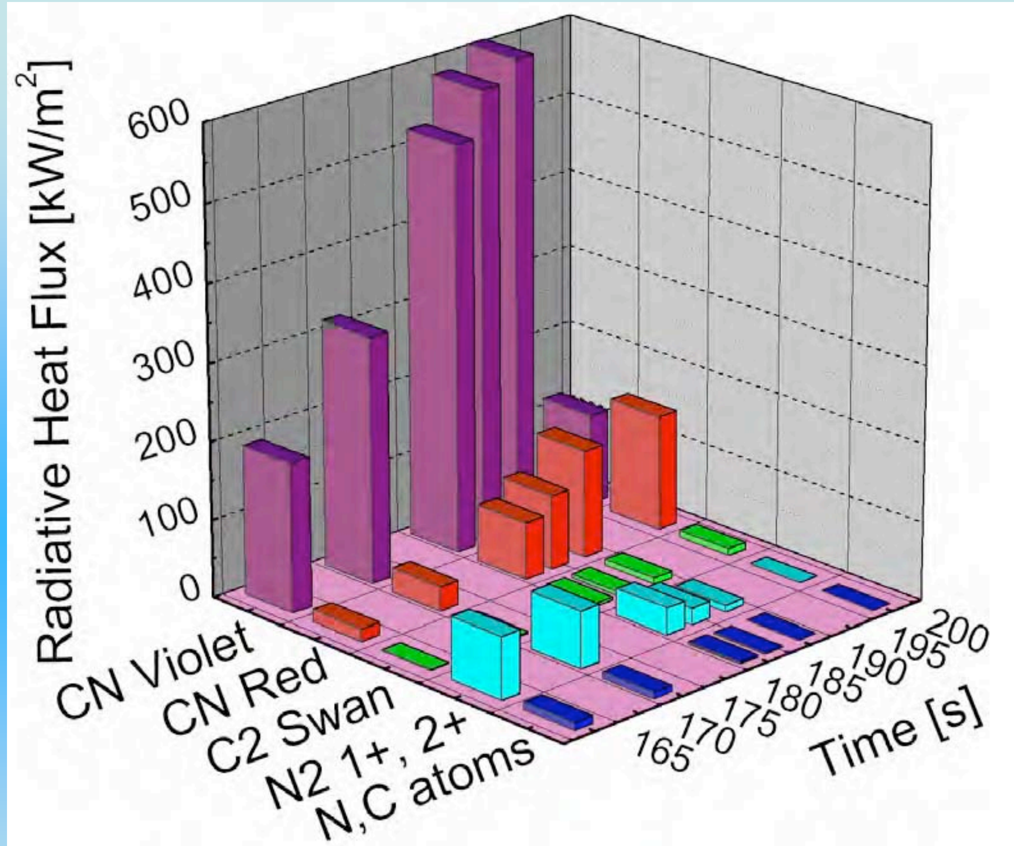
Diffusion modeling sensitivity



- SPECAIR: line-by-line radiation code (Laux, VKI lecture series, 2002 and “Optical Diagnostics and Radiative Emission of Air Plasmas,” Ph.D. Thesis, Stanford University, 1993)
- All SPECAIR simulations are obtained with:
  - Boltzmann distributions at $T_{elec}=T_{vib}$ and $T=T_{rot}$
  - Spectral resolution: 400 points/nm
  - Self-absorption
  - Spin-splitting
  - 1D tangent slab approximation

Transitions considered in SPECAIR for Huygens Simulations

- CN: Violet and Red
- N_2: 1st and 2nd positive
- NH: A-X
- C_2: Swan
- Atomic lines of N and C

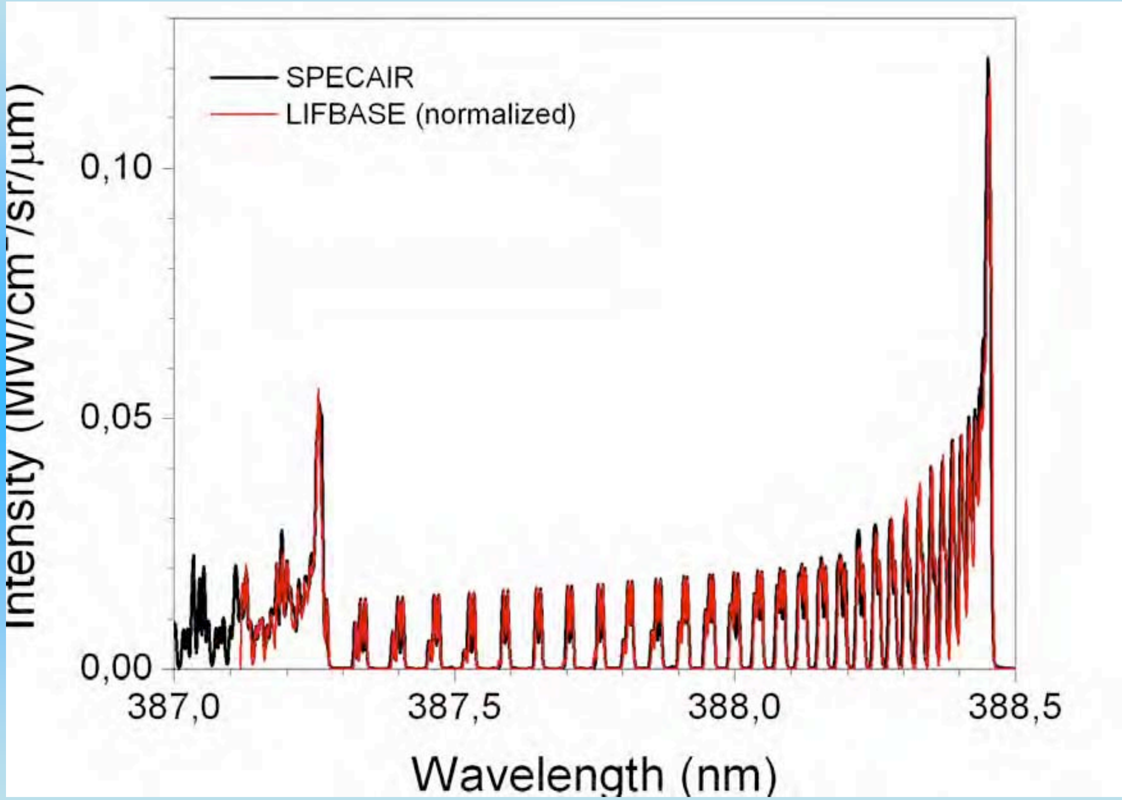


Contributions of individual species to radiative heating

(Post Ta(B) [97.2-1.8-0] -65 NoGW)

Validation of CN Violet in Relative Intensity: SPECAIR / LIFBASE*

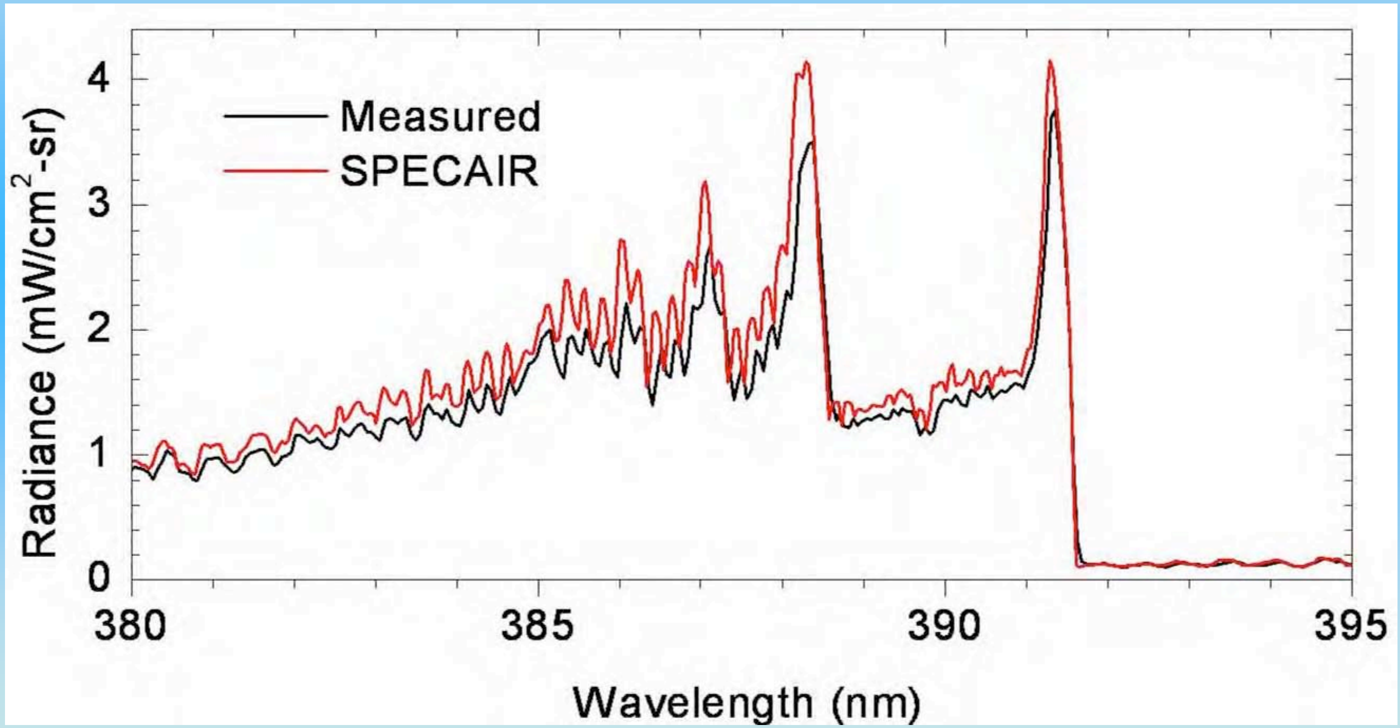
CN violet, T=Trot=7000 K, Tvib=Telec=4000 K, P=1atm



*J. Luque and D.R. Crosley, "LIFBASE: Database and spectral simulation, SRI International Report MP 99-009 (1999)

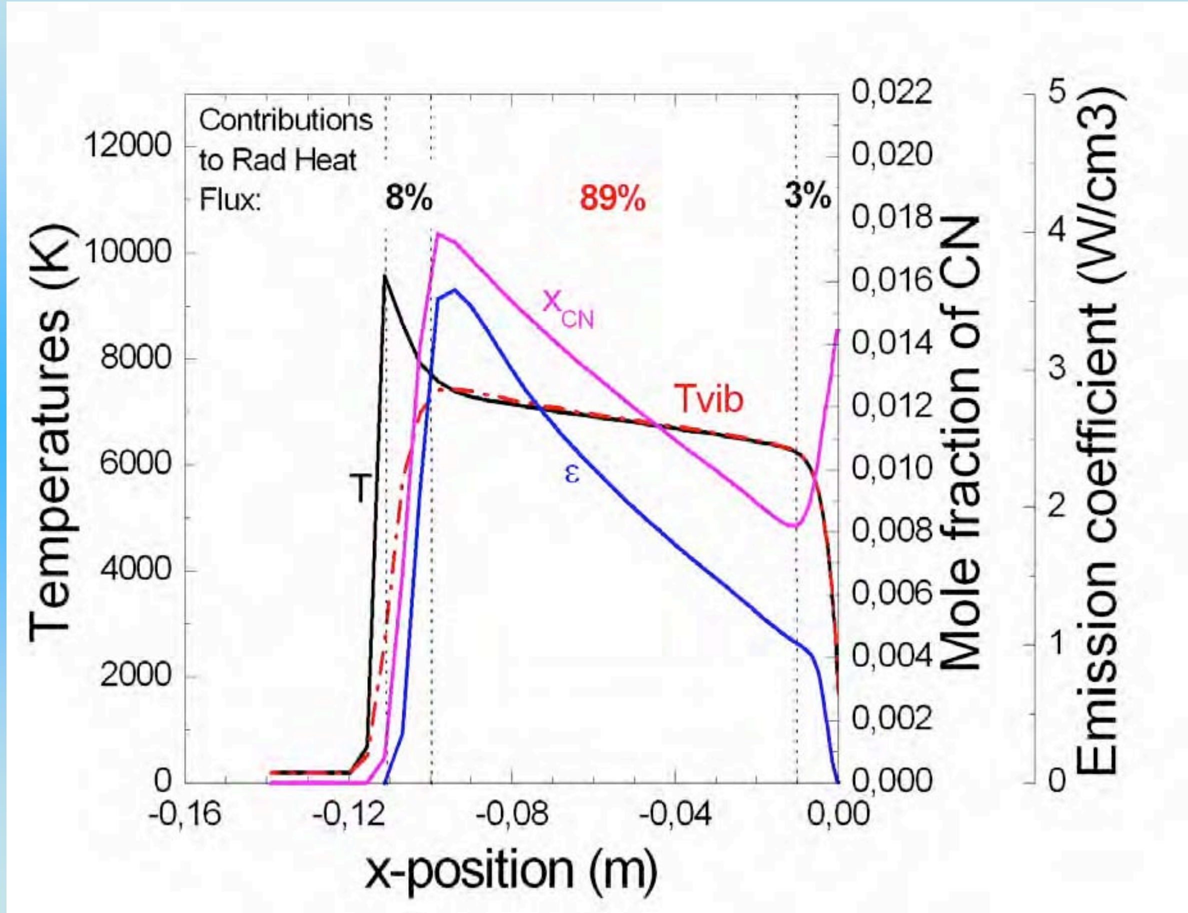
Validation of CN Violet in Absolute Intensity

Comparison of SPECAIR with LTE spectrum measured in Stanford's 50 kW Plasma Torch Facility (air with 330 ppm CO2) (Laux, VKI Lecture Series 2002)



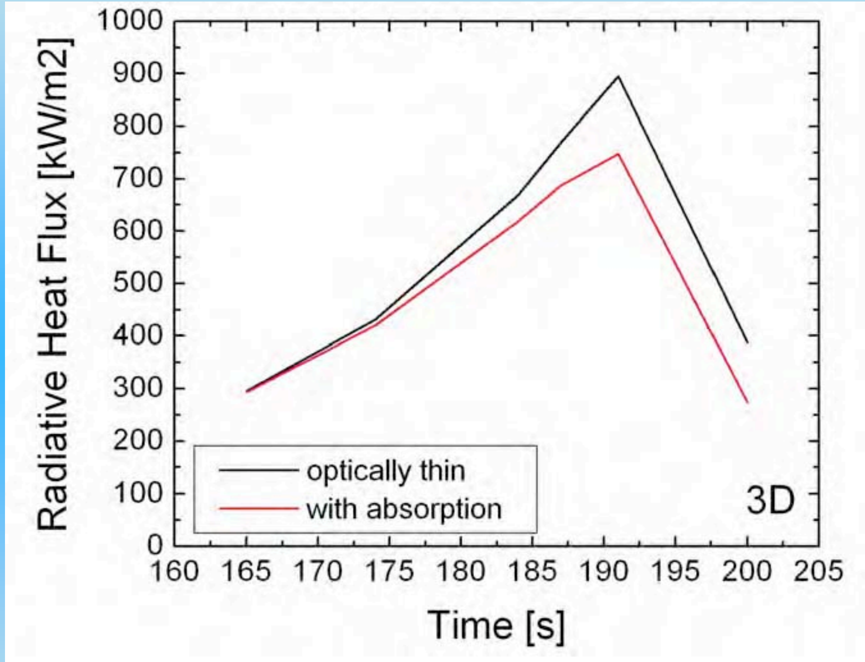
Emitting regions in the shock layer

Post Ta [97.8-2.2-0] -65 NoGW

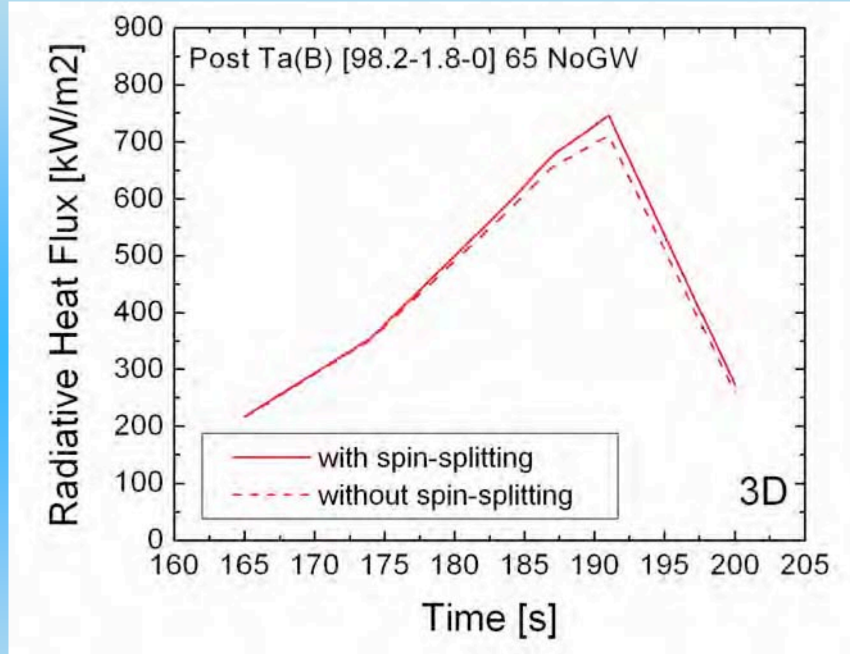


Effect of absorption and of spin-splitting

Effect of absorption

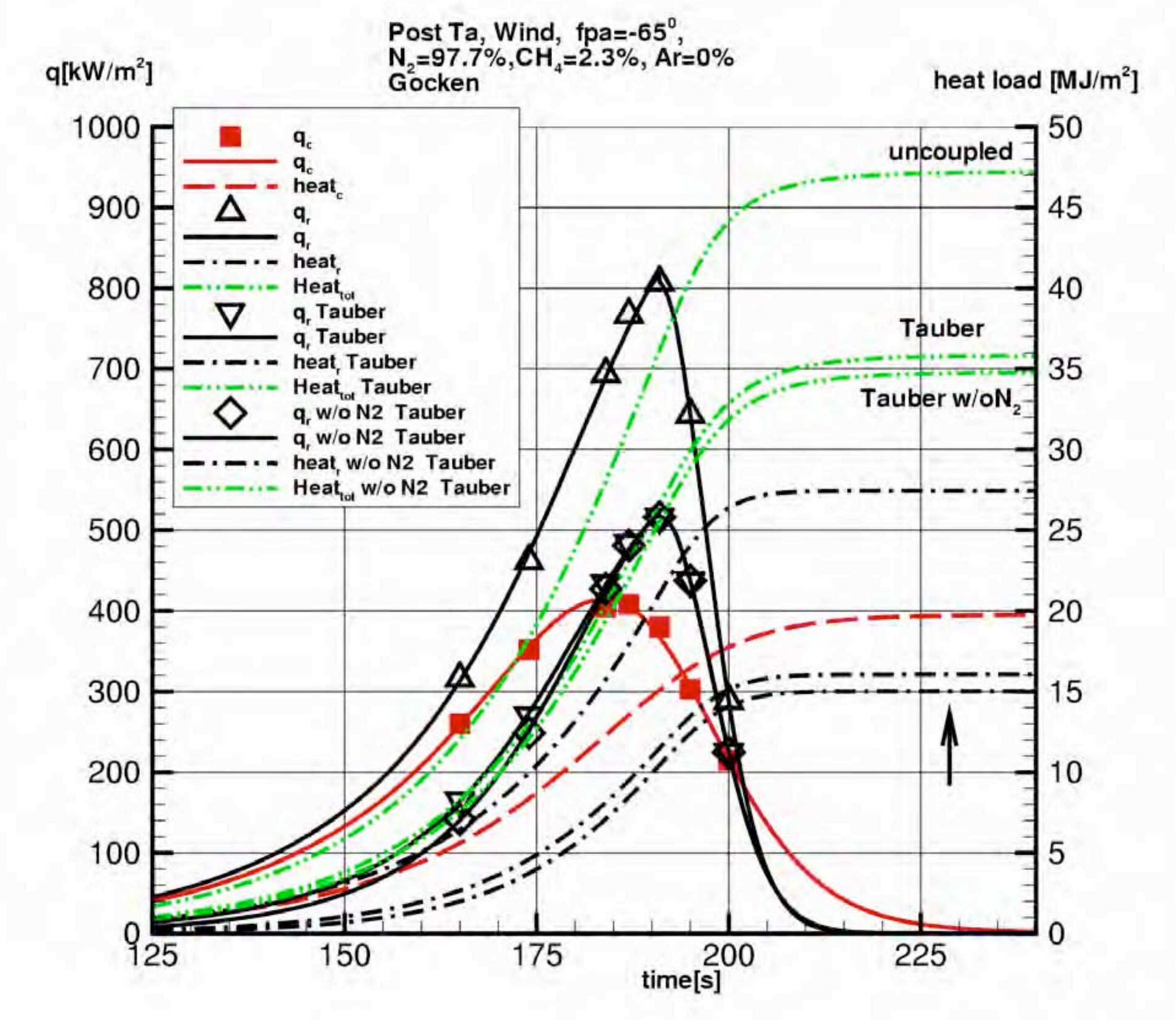


Effect of spin-splitting

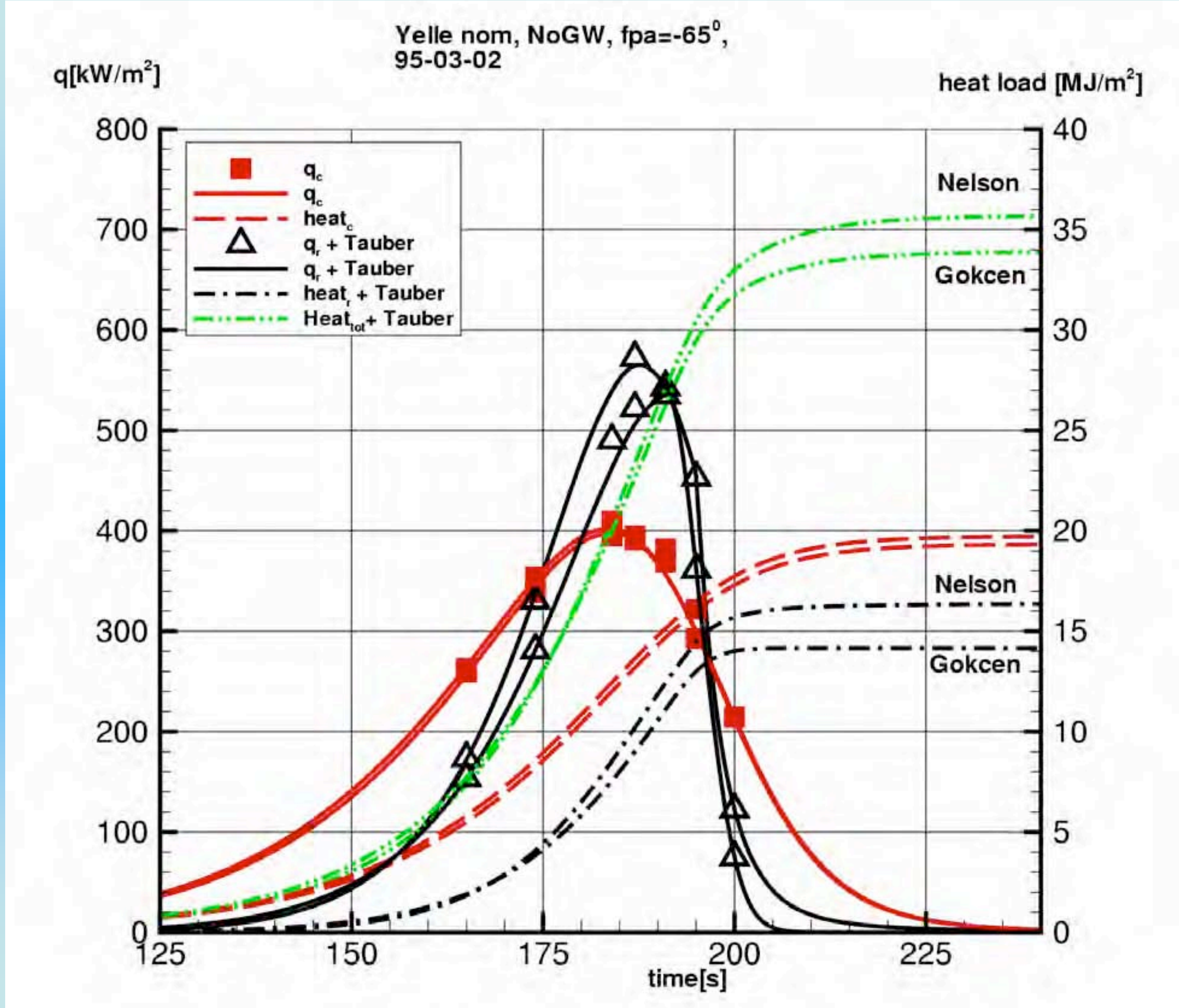


Post Ta(B) [97.2-1.8-0] -65 NoGW

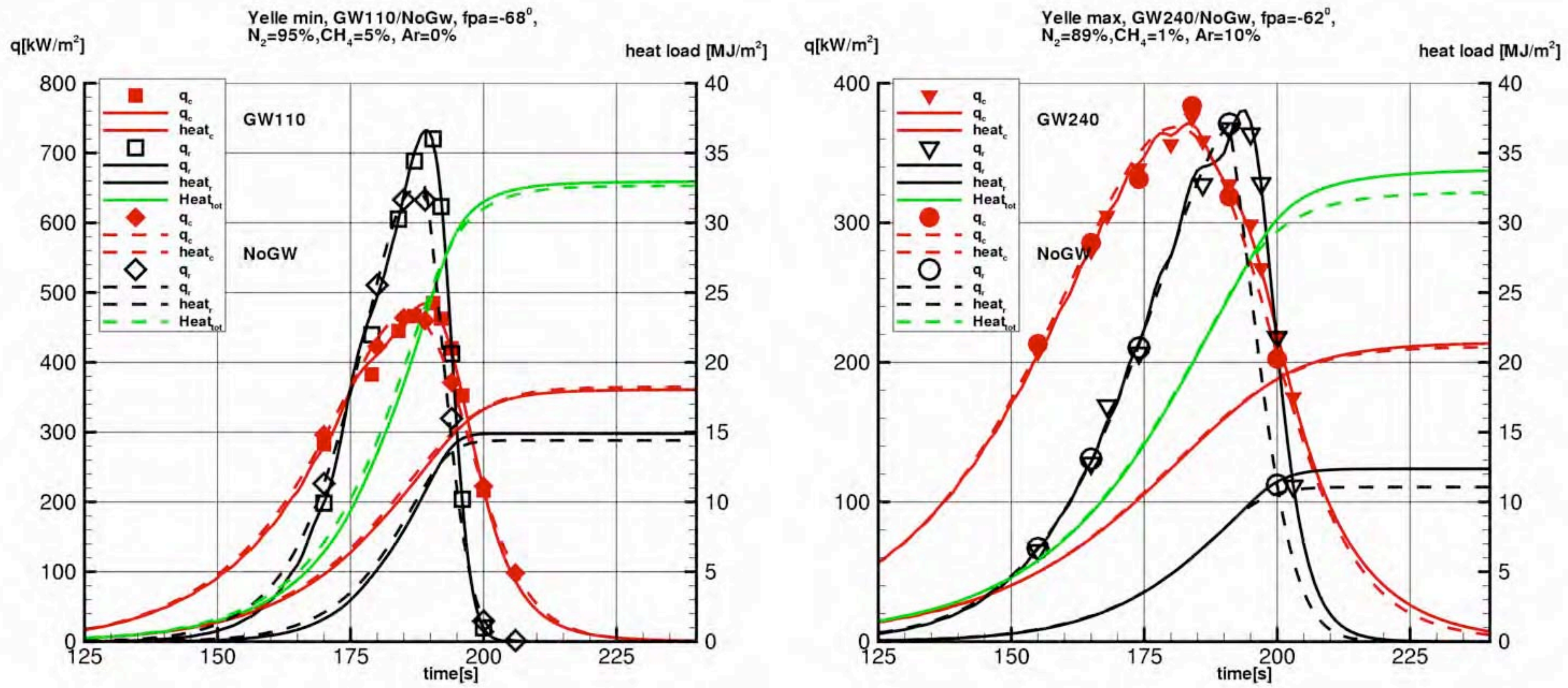
radiative relief:
coupling: Tauber/Wakefield + N2 quenching



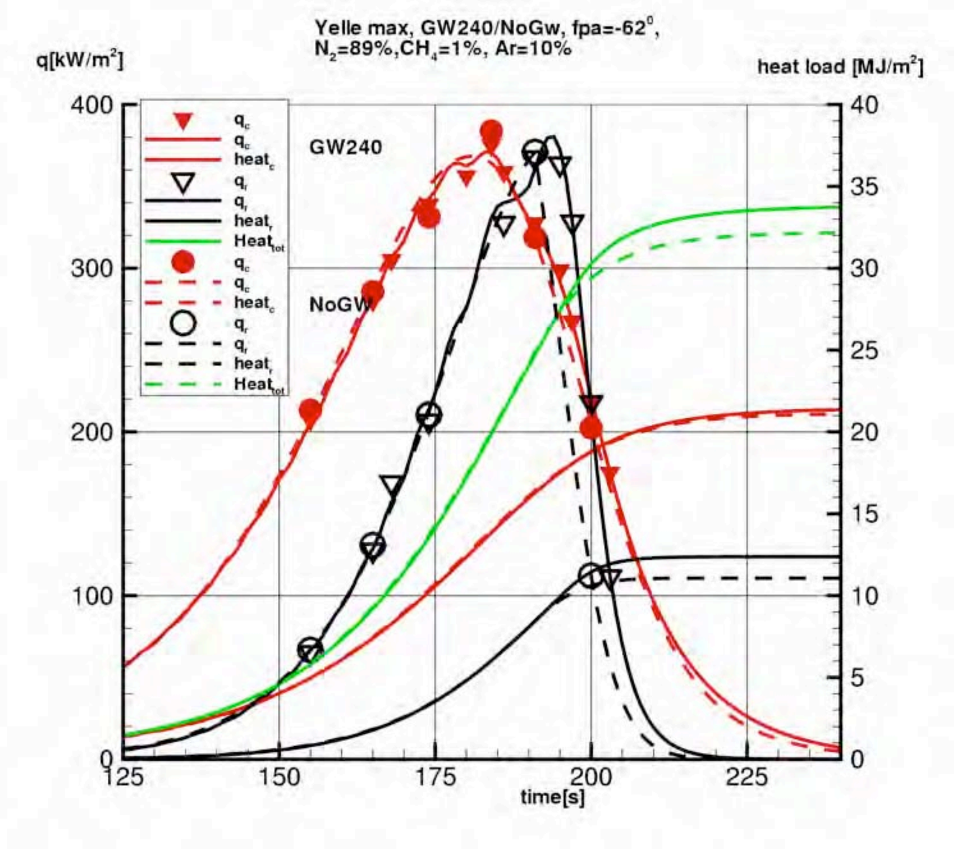
Nelson(1991)/Gocken(2004) reaction rates
Yelle nominal FPA=-65^0

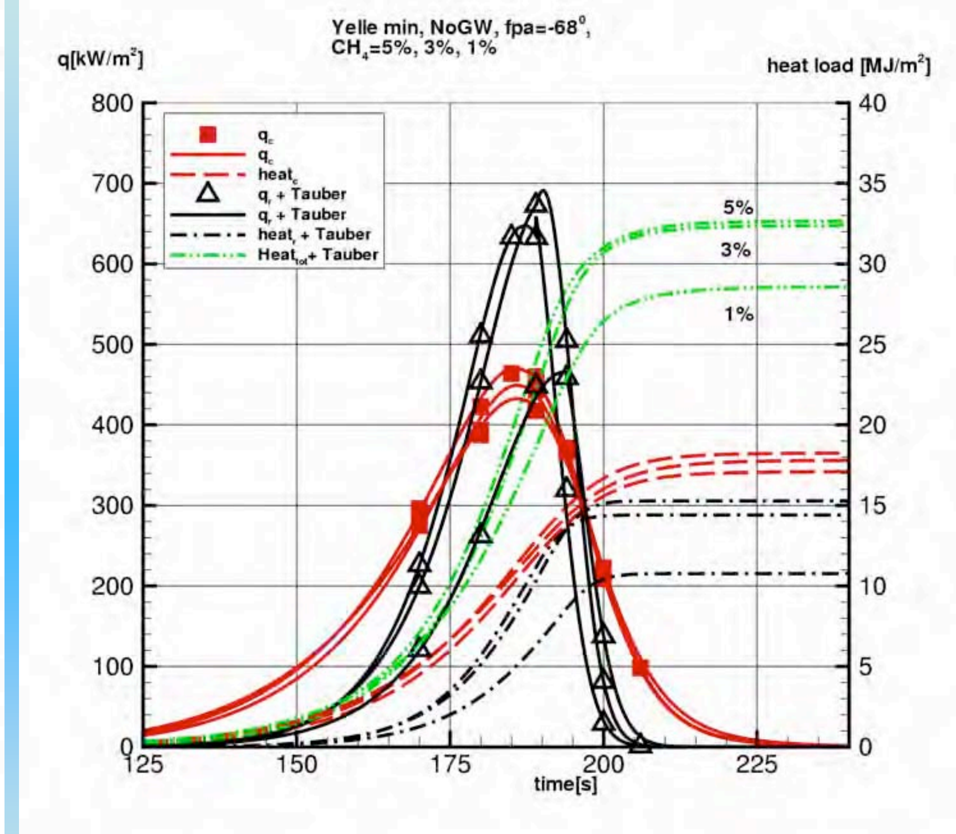


Gravity wave sensitivity: Yelle min FPA=-68 Yelle max FPA=-62^{0}

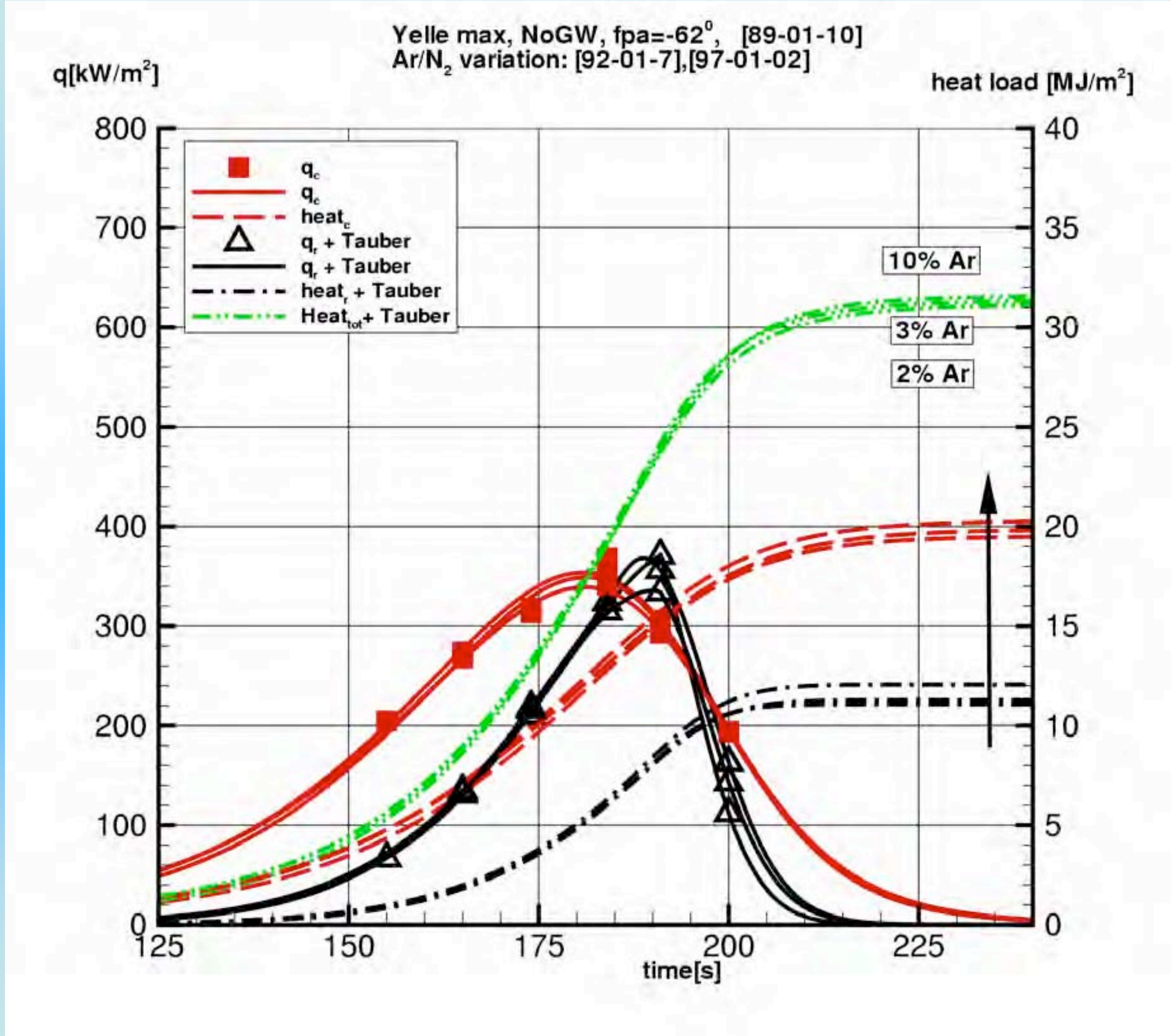


CH4/N2 sensitivity: Yelle minimal FPA=-68^0

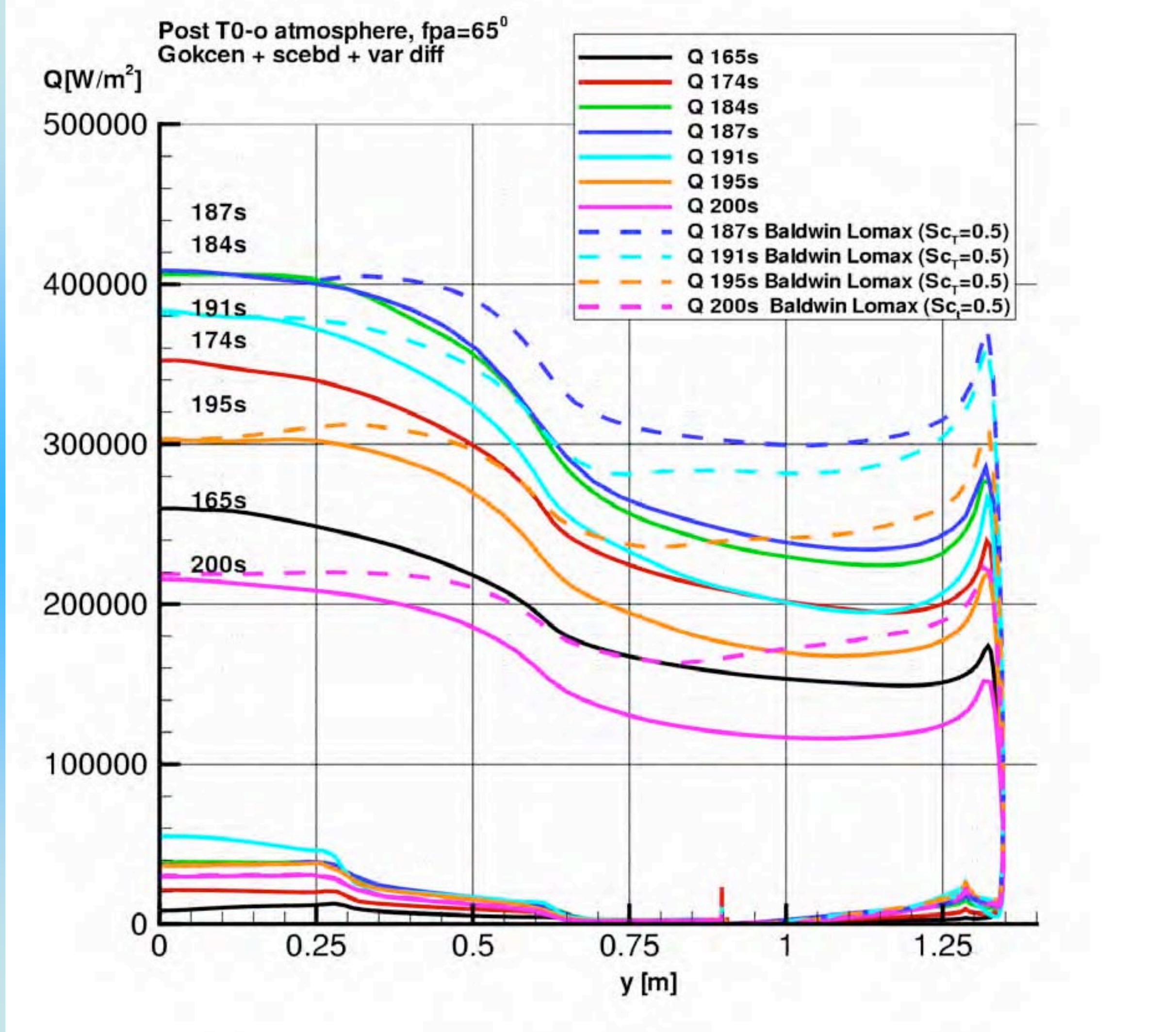




Ar/N2 sensitivity:
Yelle max: FPA=-62^0



Post TA: FPA=-65^0
convective heat flux along wall



Post TA: FPA=-65^0
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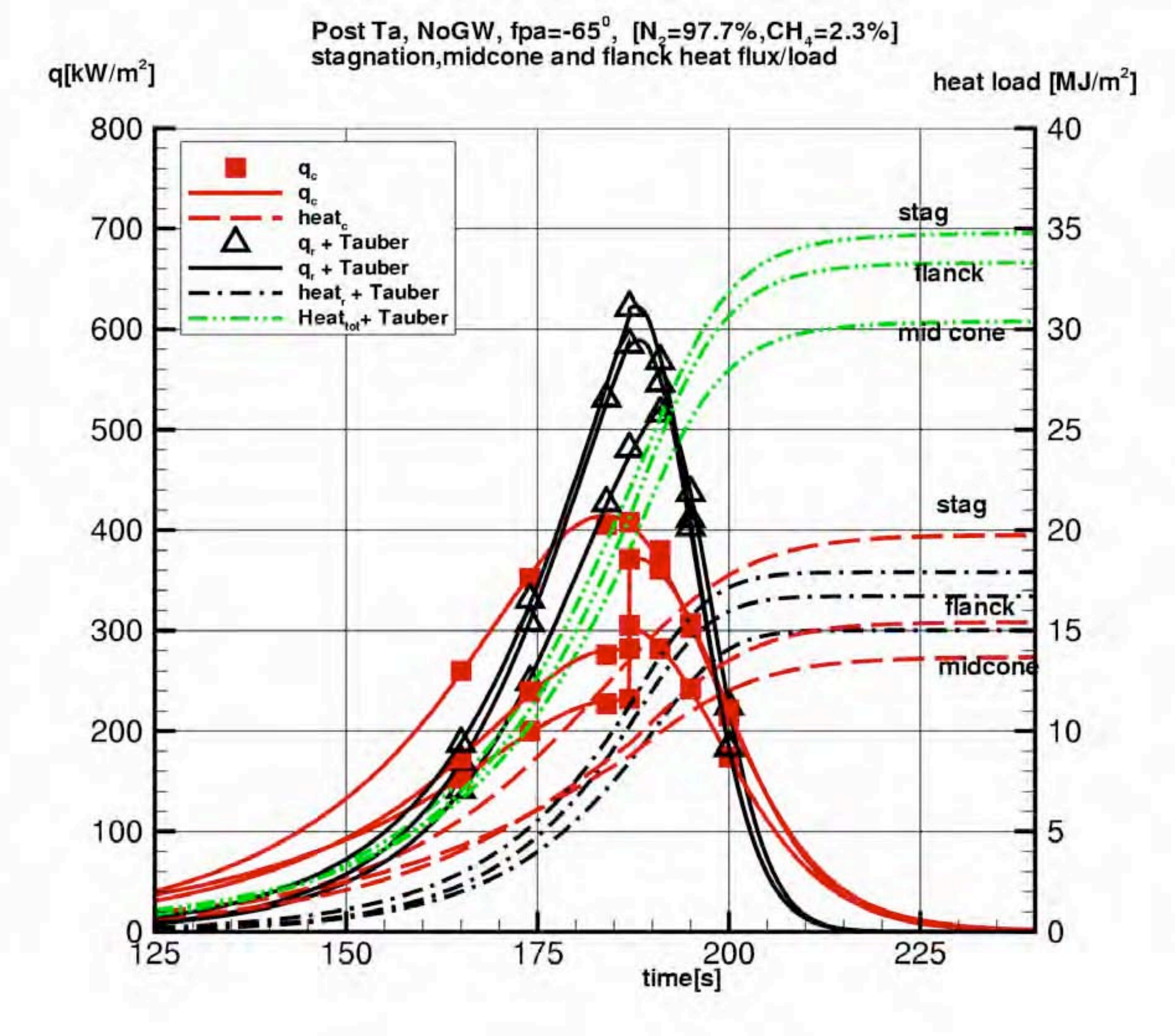
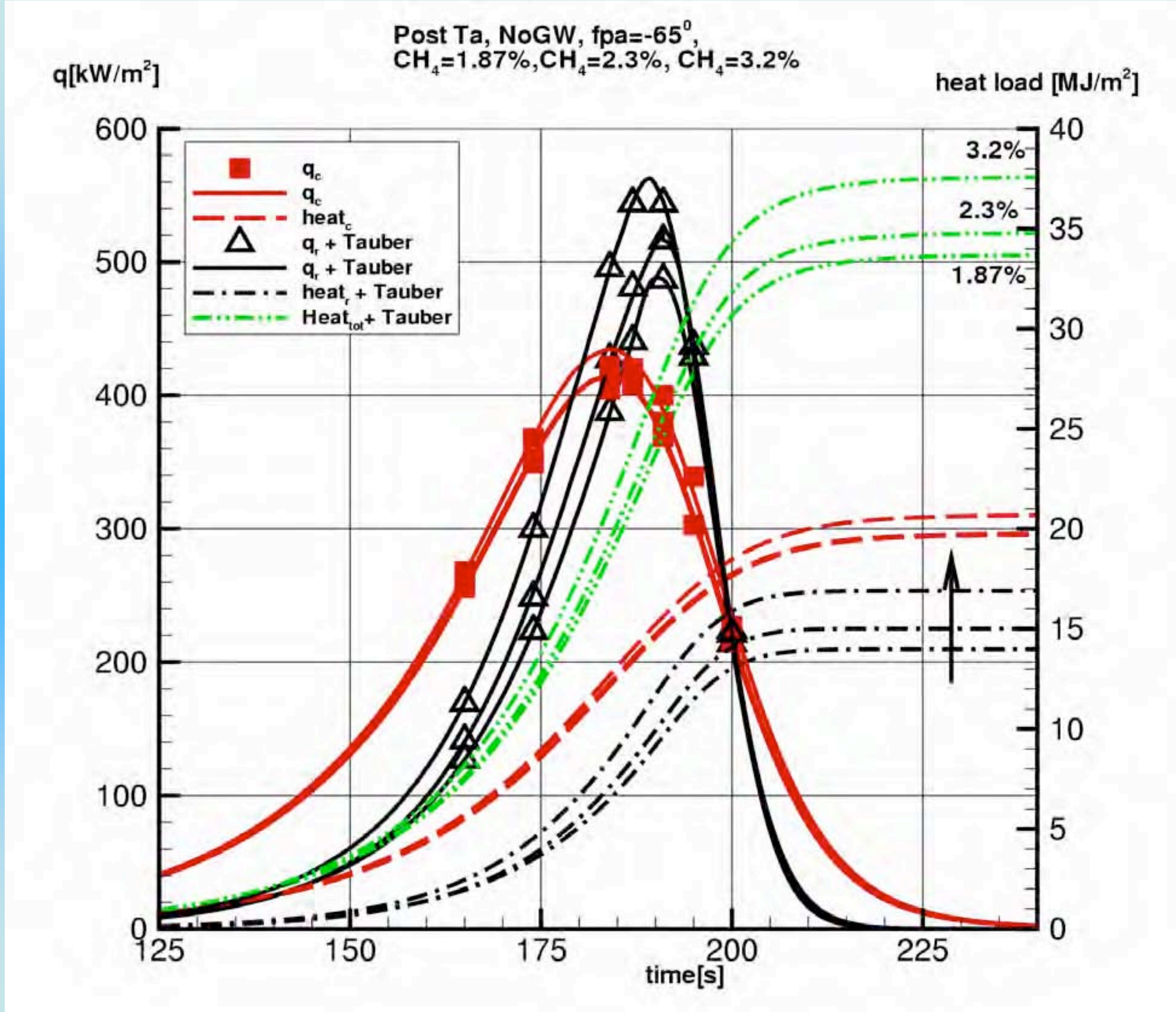


Post TA: FPA=-65^0

influence CH4/N2



Conclusions:

1. Flight Path Angle at Entry Interface variation in the range [-68,-62]: small
2. Gravity Wave perturbation sensitivity: small
3. Sensitivity to CH4: large, Ar concentration: small
4. Transport properties modeling important for accounting for diffusion of H atoms in the boundary layer. (25% stag, increase for qconv)
5. Spectral resolution, spin-splitting effect on radiative heating
6. Sensitivity to chemical kinetics modeling (Gokcen/Nelson)
7. Heat load Relief: radiation coupling modeling 25% , possible N2 quenching (5%)

Remark: ablative AQ60 heat shield injected materials not included in analysis but expected beneficial (potential radiation absorption/shielding effects)